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HYPOTHETICAL AIR INGRESS SCENARIOS IN ADVANCED MODULAR HIGH TEMPERATURE GAS COOLED REACTORS*

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ABSTRACT

Considering an extremely hypothetical scenario of complete cross duct failure and unlimited air supply into the reactor vessel of a modular high temperature gas cooled reactor, it is found that the potential air inflow remains limited due to the high friction pressure drop through the active core. All incoming air will be oxidized to CO and some local external burning would be temporarily possible in such a scenario. The accident would have to continue with unlimited air supply for hundreds of hours before the core structural integrity would be jeopardized.

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*This work performed under the auspices of the Nuclear Regulatory Commission

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INTRODUCTION

One of the potentially dangerous accident scenarios for high temperature gas cooled reactors (HTGR) has always been the case of air ingress. Reaction of oxygen with the graphite of the core and support structure can lead to weakening of the structure, egress of combustible gases (CO), and to further core heatup and fuel failures. As in previous designs, the current modular HTGR (MHTGR) design precludes significant air ingress from being a credible event. It would require the simultaneous failure of the reactor vessel in top and bottom locations, or a complete double guillotine break of the short cross duct, which is built to vessel specification. While such accident scenarios are considered to be of extremely low probability, they have been evaluated to establish whether any traumatic consequences are to be expected.

For a description of the current MHTGR concepts, the reader is referred to Ref. 1. To evaluate a massive air ingress scenario, it was assumed, non-mechanistically, that the cross duct had suffered a double guillotine break, and the steam generator side of the duct had disappeared. A scenario achieving this would require extremely destructive forces, and it may not be credible to stipulate such an event without considering also destruction of reactor vessel supports and reactor internal components. However, such an event is stipulated here, to serve as an upper bound on potential air ingress

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*This work performed under the auspices of the Nuclear Regulatory Commission scenarios. Following such a cross duct break, gas would enter the inner part of the annular cross duct, flow upward through the core, downward at the core barrel, and discharge through the outer section of the cross duct. At this exit significant recirculation would occur, with part of the inflowing gas being exhaust gas. Again, non-mechanistically, this recirculation as well as the fact that the fresh air inventory in the silo cavities is very limited are being disregarded, and pure air inflow into the inner section of the cross duct is assumed.

THE MODEL

Following such a break, the gas flow through the active core is determined by a balance of buoyancy and friction forces, which are in turn dominated by the temperature field of the large thermal capacitances of the core. Depending on the temperature level, the chemical reaction between oxygen and core graphite is governed predominantly by the chemical reactivity of the graphite (low temperature region), by the in-pore diffusion of gas through graphite coupled with the chemical reactivity (intermediate temperatures), or by the coolant to graphite surface mass transfer (high temperature region).

The analysis of gas flow through the reactor with mass transfer and chemical reaction in the core is carried out in the FLOXI code, which uses a depressurized core heatup temperature profile computed by the THATCH code. This quasi-static model neglects the thermal energy release from the exothermal carbon/oxygen reaction, which is always small with respect to decay heat. It does, however, include the effect of additional gas generation from the chemical reaction and its effect on the total flow field. Following Ref. 2, the effects of in-pore diffusion and chemical reaction are modelled by a single semi-empirical Langmuir-Hinshelwood type expression. For mass transfer in the coolant channels the binary diffusion coefficients of oxygen in nitrogen were based on Chapman-Enskog kinetic theory. Only the reaction of C and O_2 to CO was considered here. At the prevailing temperature levels any CO_2 formed initially would typically react to CO in the hotter core regions. For the total burn-off, as well as the amount of combustible gases formed, neglecting any small CO_2 fractions in the exhaust gas is conservative.

RESULTS

Applying the FLOXI code to a typical core heatup transient resulting from the assumed cross duct failure the core gas flow and graphite oxidation transients of Figure 1 were obtained. The gas flow process and the amount of graphite oxidized are under all conditions completely limited by the in-core friction pressure drop. The coolant holes are about 15 mm in diameter and almost 10 m long, and in-core flow rates are always extremely laminar with typical Reynolds numbers between 20 and 100. As the core heats up the air inlet flow rapidly decreases from about 500 kg/hr to about 250 kg/hr for most of the transient. In very early portions of the transient the exhaust gas still contains about 6 vol % of air, but as the core heats up, after a few hours all air reacts in the lower portions of the core, and most of the reactor sees a gas stream of 35 vol % CO and 65 vol % N_2. The resulting graphite oxidation rates decrease from an initial value of 80 kg/hr to about 40 kg/hr for most of the transient.

To assess the uncertainties in the graphite reactivity and the diffusion coefficients used, both were varied by up to two orders. In each case only the length of the reaction zone was affected. With lower reactivity and/or diffusion coefficient, some of the oxidation shifted from lower elevations to the center of the core. Except in the first few hours, virtually all oxygen was converted to CO, and the total in-core flow did not vary significantly, as it remained dominated by the in-core friction pressure drop. When a 50/50 gas mixture of helium and air was assumed instead of pure air inflow, the gas mass flow rates and graphite oxidation rates were about one-third of those for pure air flow. The energy release from the chemical reaction amounted to about 6% of the decay heat, justifying the assumption of neglecting this effect as well within the uncertainties of the analysis, in particular since the temperature field used here was computed with a conservative decay heat function.

CONCLUSIONS

The air inflow into the core and the subsequent graphite oxidation rates under extremely pessimistic accident assumptions remain limited by the in-core friction pressure drop of the long and narrow coolant channels.

All air entering the core will be oxidized except during the first few hours of the transient. As the air supply in the reactor cavity is in general limited, the reactions would come to a halt well before the 200 hr transient considered here. Significant loss of strength of the graphite structures could become a concern only if an unlimited air supply would be available for hundreds of hours. Also, during the initial phases of such an accident, as the available air in the reactor cavity is burnt and CO is emitted from the reactor, local burning in the reactor cavity would not be impossible.

Even under the above extreme assumptions, such an accident could not lead to any rapid destruction of the core or to significant fission product releases.

REFERENCES

1. Bechtel National, Inc. et al., "HTGR Concept Descriptive Report," DOE-HTGR-86-118, October 1986.

2. W. Katscher, R. Moormann, "Graphite Corrosion Under Severe HTR Accident Conditions," Paper presented at the IAEA Specialists' Meeting on Graphite Component Structural Design, JAERI, Tokai-mura, Japan, September 8-11, 1986.

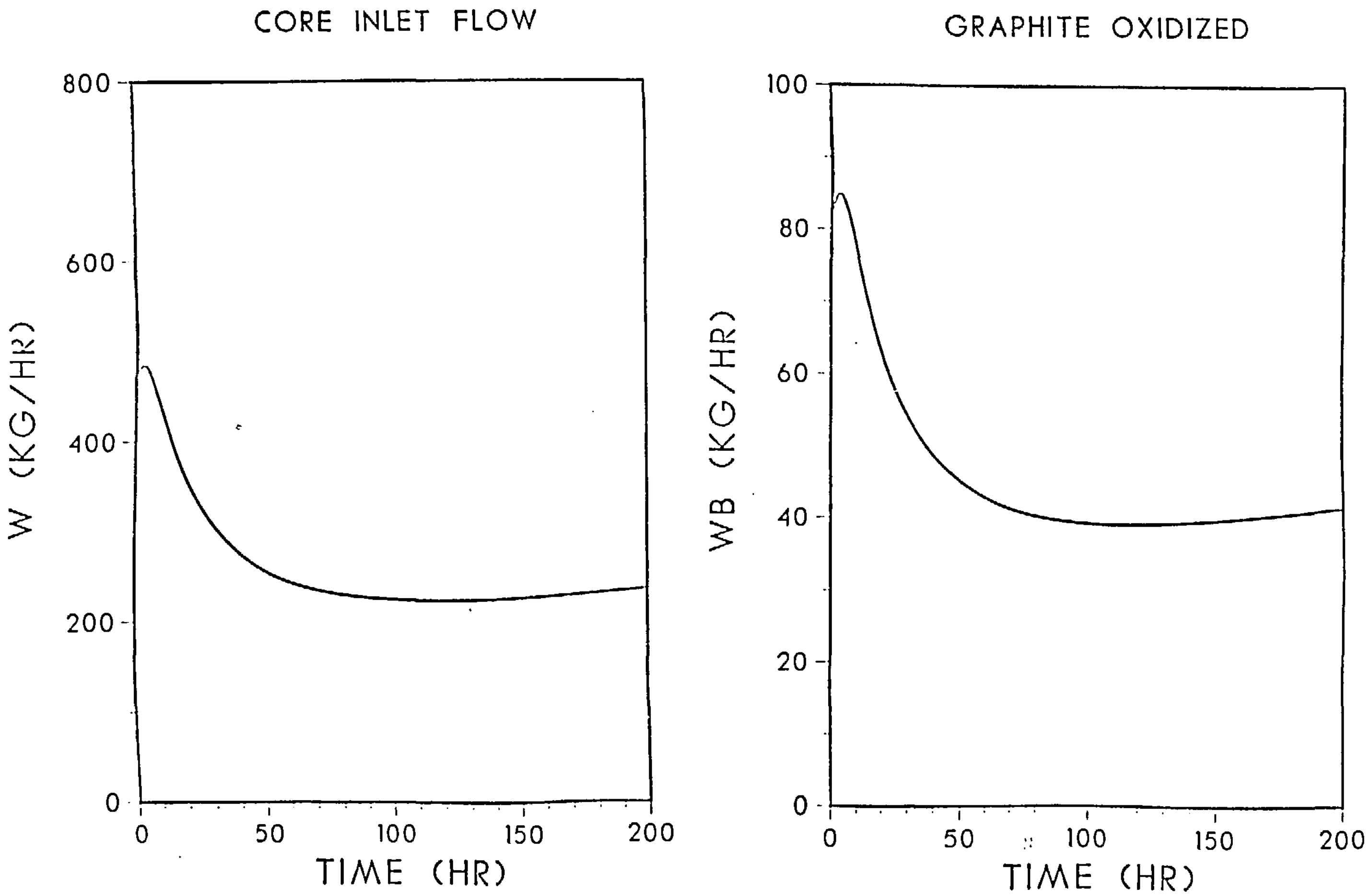

Figure 1: Core Air Inlet Flow, and Graphite Oxidation Transient Subsequent to Complete Cross Duct Failure